THE EFFECT OF CELL GEOMETRY ON DEPOSIT THICKNESS UNIFORMITY IN A WAFER PLATING CELL

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The geometric design of a wafer plating cell has a significant influence on the thickness distribution and uniformity of the electrodeposited metal. This paper describes a series of finite difference calculations used to model the effects of anode size and position as well as cathode shielding on the current density distribution in an axisymmetric cell. An optimum cell design can be determined based on these calculations. The effects of the electrolyte conductivity and kinetic parameters will also be discussed.

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The thickness distribution of electrodeposited metal on semiconductor wafers is influenced strongly by the geometric configuration of the plating cell. Previous work has shown that the current density distribution calculated using the finite difference method gives a good approximation of the deposit thickness distribution.(1) These calculations showed how the uniformity of the current density distribution is influenced by the diameter of the anode and its distance from the cathode as well as by cathode shielding. The major purpose of the previous work was to demonstrate the validity of calculating the current density distribution using the finite difference method as a tool for modeling the deposit thickness distribution on a circular cathode in an axisymmetric cell. This paper describes additional calculations using the same method of modeling to find the geometric configuration for a cell that will produce the most uniform current density distribution.

A cross-section of the cell geometry used in these calculations is shown in Figure 1. For simplicity, the wafer diameter was held constant at 20 cm (8 inches) and the cell diameter was fixed at 25 cm (10 inches) for all calculations presented in this paper. Four geometric variables were considered as shown in Figure 1. These were (1) the cell height which is the anode-to-cathode spacing, (2) anode diameter, (3) the diameter of the opening in the annular ring cathode shield, and (4) the distance between the cathode and the bottom of the shield. The thickness of the shield also has an effect on the current density uniformity as will be discussed below.

The effect of electrolyte conductivity on the current density distribution can also be considered using this model. The correlation equation determined by Hsueh(2) for the conductivity of solutions containing copper sulfate and sulfuric acid provides a convenient method for calculating the conductivity of baths over the range of concentrations of interest for practical electrodeposition. When considering the effect of electrolyte conductivity on the current density distribution, the voltage between anode and cathode must be varied appropriately in order to maintain a relatively constant current density.

Evidence in the literature indicates that the exchange current density for the copper deposition reaction is also dependent on the concentrations of copper sulfate and sulfuric acid. Cabán and Chapman(3) fitted exchange current data from several sources to a semi-empirical equation to calculate the exchange current densities over a range of electrolyte compositions. Their equation was used to calculate exchange current densities for the various electrolyte compositions considered in this work. Table 1 shows the bath compositions considered in this work along with their calculated conductivities and exchange current densities. The correlation equations were derived from data on solutions containing no additives.

Table 1. Bath Compositions and Properties

Bath	1	2	3
Copper Sulfate, M	0.30	0.63	1.0
Sulfuric Acid, M	1.8	1.0	0.76
κ, mho/cm	0.563	0.323	0.235
i_o, ma/cm^2	3.83	7.91	11.76

The cathodic transfer coefficient for copper deposition from additive-free acid sulfate solutions is reported to be 0.5 over a wide range of solution compositions.(4, 5, 6) Therefore a Tafel slope of 0.118 volt/decade at 25 °C is appropriate for the calculations of this work.

However, the presence of organic additives can change both the Tafel slope and the exchange current density.(7) The Tafel slope is often in the range of 0.140 to 0.150 or greater(8) and the exchange current density is decreased in the presence of adsorbable organic compounds. For this reason, the effect of these factors should also be considered when determining the optimum cell configuration.

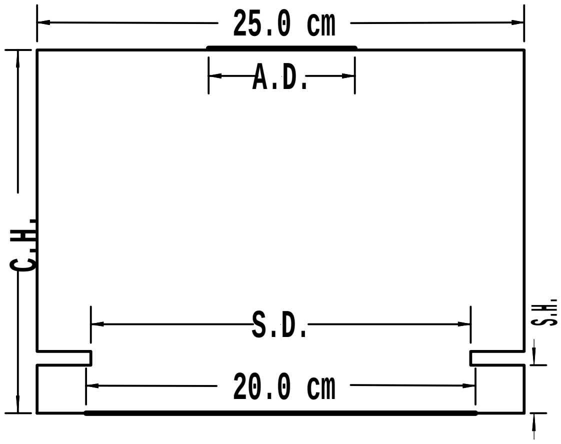

Figure 1. Cross-section of wafer plating cell showing fixed dimensions and dimensions to be optimized. C.H. – cell height; A.D. – anode diameter; S.D. – shield diameter; S.H. – shield height.

Table 2 shows optimum values of the four variable dimensions of cells having the geometry shown in Figure 1 for plating copper on wafers from the three electrolytes listed in Table 1.

Table 2. Optimum cell dimensions for different electrolytes

Electrolyte	1	2	3
Cell height, cm	12.75	12.5	12.75
Anode diameter, cm	9.5	10.0	9.5
Shield height, cm	1.75	1.75	1.75
Shield diameter, cm	19.5	19.5	19.5

Plots of the current density distribution across the wafer surface for each of the three electrolytes are shown in Figure 2.

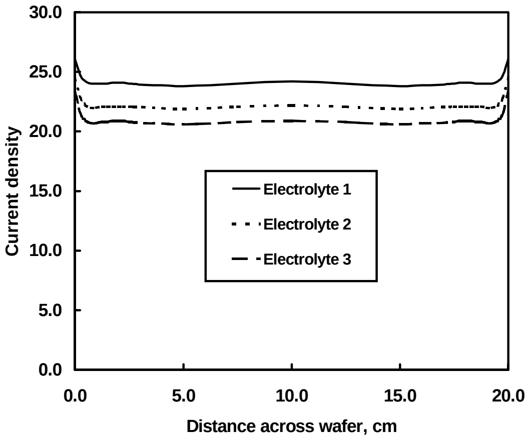

Figure 2. Current density distribution across a wafer plated in a cell whose geometry is optimized for each electrolyte.

A convenient way of determining the uniformity of the current density distribution is to calculate the ratio of the minimum current density to the maximum current density across the wafer surface excluding the region less than 0.6 cm from the edge of the wafer. The closer this ratio is to unity, the more uniform is the current density distribution across the wafer. The min/max ratios for the optimized cell dimensions for each of the three electrolytes are:

Electrolyte 1	0.9850
Electrolyte 2	0.9846
Electrolyte 3	0.9843

Since these ratios are very nearly equal, it should be possible to obtain uniform current density distributions from a fairly wide range of electrolyte compositions.

The effect of variations in cell geometry on current density uniformity is shown in Tables 3 and 4. These tables show how the min/max ratios change when the geometric dimensions of the cell are changed slightly from the optimum dimensions.

Table 3.
Effect of Varying Cell Height and Anode Diameter on Current Density Uniformity (Electrolyte 1)

	Cell Height, cm		
Anode Diameter, cm	11.75	12.75	13.75
8.5	0.9448	0.9807	0.9694
9.5	0.9543	0.9850	0.9650
10.5	0.9697	0.9786	0.9594

Table 4.
Effect of Varying Shield Height and Shield Diameter on Current Density Uniformity (Electrolyte 1)

	Shield Height, cm		
Shield Diameter, cm	1.25	1.75	2.25
19.0	0.8954	0.9277	0.9362
19.5	0.9591	0.9850	0.9664
20.0	0.9093	0.9236	0.9202

The ratios shown in Tables 3 and 4 indicate that the current density uniformity is sensitive to small changes in cell geometry. Changing the anode diameter by one centimeter decreases the min/max ratio by less than one percent. Changing the cell height by one centimeter decreases the ratio by about three percent. A one-half centimeter change in shield height reduces the ratio by two to three percent. The most sensitive dimension is the diameter of the shield opening. Changing this dimension by one-half centimeter reduces the min/max ratio by about six percent. The diameter of the shield opening determines the current density near the edges of the wafer where it is changing most rapidly. Therefore, this is the most critical dimension that must be optimized for current density uniformity. Figure 3 shows how varying the shield-opening diameter affects the current density distribution across the wafer surface. If the opening is less than optimum, the current density is too low at the edge of the wafer; if the opening is larger than optimum, the current density is too high on the wafer edge.

The thickness of the shield also has an effect on the uniformity of the current density distribution.

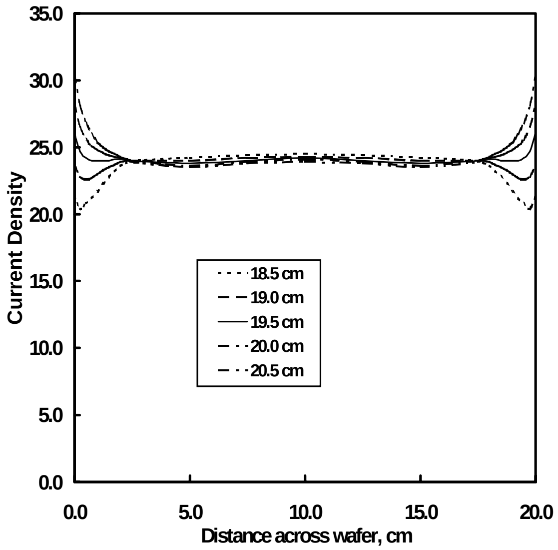

Figure 3. Effect of various shield-opening diameters on the current density distribution across a wafer surface.

Table 5 shows the min/max ratios for three different shield thicknesses in cells having optimum geometry for each of the three electrolytes considered in this paper. As with other variable dimensions, a change in either direction from the optimum value reduces the value of the min/max ratio.

Table 5.
Effect of Shield Thickness
On Current Density Uniformity

	Shield thickness, cm		
Electrolyte	0.25	0.50	1.00
1	0.9259	0.9850	0.9518
2	0.9507	0.9846	0.9484
3	0.9494	0.9843	0.9461

Conclusion

Finite difference calculations have been used to determine the optimum cell geometry to obtain the most uniform current density distribution over a semiconductor wafer in an axisymmetric cell. These calculations indicate that a cell with an optimized configuration can be used with plating baths having a fairly wide range of compositions. These calculations which were implemented on a personal computer show that an optimum cell design can be determined in a relatively simple manner for use as a starting point for experimentally optimizing a plating cell. The finite difference method of calculation is applicable to other cell geometries and should find wide application when it is necessary to design plating cells in which critical uniformity must be maintained.

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